International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 10, Issue 2, Apr 2020, 655-670

ROLE OF NANOPARTICLES ADDITIVES WITH BIODIESEL BLEND AS AN ENGINE FUEL: COMBUSTION AND IGNITION CHARACTERISTICS OF ENGINE PERFORMANCE AND EMISSIONS

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ABSTRACT

Biodiesel as a fuel has the potential to reduce emission and can be utilized as an alternative for the conventional fuel source. It also reduces greenhouse gas emissions. To reduce the harmful effect of the emissions, and to have an enhancement in combustion characteristics, Nanoparticles can be blended with biodiesel. An in-depth analysis of the evaporation and combustion characteristics of the fuel with the addition of Nanoparticles is critically observed in the paper from the recent research. Biodiesel from various feedstock to some extent lower brake power and BTE, also increases BSFC than diesel and reduces the PM, HC, CO, and CO2 emissions but gives slightly higher NOx emissions. The usage of Nanoparticles with Biodiesel, EGR and engine design modification may be an alternative for the NOx reduction. This pape ris focussed mainly on reduction in emission and enhancement in performance with the use of Nanoparticles.

KEYWORDS: Biodiesel, Nanoparticles, Emission, Combustion Characteristics & Evaporation

Received: Jan 23, 2020; **Accepted:** Feb 13, 2020; **Published:** Mar 17, 2020; **Paper Id.:** IJMPERDAPR202057

Original Article

INTRODUCTION

In the modern era, the main focus is to fulfill the growing needs and to reduce the environmental impact. There are few alternatives aimed at the reduction of pollutant emissions [1]. The diesel engine is used in the transportation and power sector, because of its main benefits over other engines such as lower fuel consumption, high reliability and high BTE due to the use of high compression ratio and lean air-fuel mixer. Air pollution is a major issue with the current stringent norms of emission now-a-days. It also affects climate change, and many biological species and human's life. Due to the use of automobile vehicles, its combustion and its emission will be almost double in magnitude in the year of 2031-32. For the reduction of emission, Researcher mainly focused on the: change in the design of the engine, developing new alternative fuels with good characteristics, and improvement in the EGR technique [2]. Biodiesel is one of the best available options with the property that can run well with Diesel engine without any change in it [3]. It can be easily stored and produced. For edible oil, Palm oil has the highest yield 5000 kg per hectare and for non edible oil, Jatropha has highest yield of 1590 kg per hectare [3]. Many researchers working on fuel blending to achieve specific property which gives the optimized result to fulfill the above criterion without making any change in the engine design [4]. With the addition of Nanoparticles into diesel, there is a marked improvement found in the main thermophysical properties and improvement in other properties of fuel blends, which affect the above factors [4]. Nanoparticle's dose, size, and volume are parameters to be considered for emission. Emission, mainly composed of the volatile materials are formed as the exhaust dilutes and cools in the

exhaust. The emission amount and size formed are mainly affected by this process. Thus, atmospheric dilution should be kept in check to make a green and clean environment [5]. Up to 20% dose of Nanoparticles, fuel rate is decreased by 1-2 % due to the reasons such as better fuel distribution, lower ignition delay time and change in the fuel's physical characteristics. These are the main factors responsible for the reduction in emission and fuel consumption. Also, Nanoparticles blended fuel can promote fuel momentum of injection and penetration rate in the cylinder, which distributes the fuel evenly in the chamber [6]. Manganese is also considered as pollutant reduction Nanoparticles; it can be used for the blend with diesel fuel. It has large potential to reduce pollutant [7].

According to the Zeldovich mechanism, NOx emission mainly formed due to the percentage of oxygen present during combustion, the time it takes for burning the fuel and temperature inside the chamber. With the addition of Nanoparticles, the temperature in the combustion chamber has reduced; it is the main reason for the reduction in NOx emission. Nanoparticles have good thermal conductivity and also it enhances convective heat transfer, it helps in the reduction of the NOx emission [6]. Also, metal Nanoparticles accelerate the fuel vaporization and have reduced delay time in the combustion [6].

COMBUSTION

In Combustion analysis, the most important properties are Ignition delay, Heat release rate and pressure inside the cylinder at a particular crank angle or P-θ diagram. Ignition Delay is defined as the period between the start of fuel injection into the combustion chamber and the start of combustion. It is the time (or crank angle) interval between the start of injection and the start of combustion [8]. The start of injection is generally taken as the time when the injector needle lifts off its seat. It is determined from the change in slope on p-θ diagram or a heat release analysis of the p (θ) data, or a luminosity detector. Depending upon the combustion process, it can be easily identified by the pressure data which may indicate when pressure change due to combustion first occurs particularly in Direct injection engines under normal conditions ignition is well defined [8]. With the addition of metallic Nanoparticles, Combustion stability can be improved for the diesel [7]. With the Nanoparticles addition, radiative and heat/mass transport properties increased due to early initiation of combustion and also due to reduced ignition time compared with diesel fuel [9]. Also, SEM analysis confirmed the increment in ignition probability [9]. In comparison with Aluminum micro particles, its Nanoparticles gave longer stable suspension in the fuel blend [10]. During combustion of Aluminum Nanoparticles suspended fuel, five stages were observed in comparison with micro suspension in which only first three stages observed. The stages were preheating and ignition, classical combustion, micro-explosion, surfactant flame, and Aluminum droplet flame [10].

NANO FUEL

Nanoscience introduces many modern technological changes that made the property change of fuels for the purpose of enhancement of the performance parameter and the reduction of harmful emissions. It is most widely employed recently in comparison to the other methods like exhaust gas treatment and engine modification [11]. Because of the use of Nanoparticles, it improves the physical properties like the surface area to volume ratio, thermal conductivity, and mass diffusivity. It also affects properties like flash point, fire point, kinematic viscosity, and other properties. Broadly, Nanoparticles are categorized as follows: i) Metal-based Nanoparticles i.e. Aluminum, iron, boron and ferric chloride, etc.; ii) Metal oxide Nanoparticles i.e. CeO_2, Al_2O_3alumina, TiO_2, MnO, CuO, etc; iii) Magnetic Nanoparticles particles i.e. Fe_3O_4; iv) Carbon Nanotube particles i.e. Single-walled and multi-walled CNT [4]. Due to high viscosity and density,

vegetable oils is used directly as an engine fuel. It causes incomplete combustion, poor fuel atomization and carbon deposition on the different fuel supply system parts like valve and injector [12]. All these problems might be reduced by the addition of diesel fuel in suitable amounts and transesterified vegetable oils into biodiesel [12]. It is a well-known fact that up to the blending of 20% biodiesel optimized results in the relation of thermal efficiency and emission compared to the higher proportion of biodiesel blends. One of the better methods to reduce emissions for biodiesel is the use of metal catalysts. It gives better efficiency and a reduction in emissions [12]. Due to the effect of Nanoparticles on Combustion, lower ignition delay period and increment in combustion peak temperature was found. [13]. One of the most important benefits of the Nanoparticles is ignition delay could be reduced. It gives improved atomization, enhanced ignition properties, and Cetane number, and also a higher surface-area-to-volume ratio [14]. With Diesel, Palm biodiesel and Iron Nanoparticles blends advance heat release and observed lower ignition delay [15]. For 35 ppm of Ce2O3 with Diesel blend gave minimum level of emission [16]. Within certain limit of dosing level of Ce2O3 Nanoparticles, increment in BTE was found [17]. HC and NOx emission reduced drastically because of the addition of more thermally stable Ce2O3 Nanoparticles which influenced oxidation of HC and reduction in temperature inside cylinder [17]. Due to addition of Alumina Nanoparticles which have higher surface area, mixture preparation and blending done without difficulty with Cashew nut shell oil bio fuel. Also, the burning rate also found to be increased due to addition of Alumina Nanoparticles with Cashew nut shell oil blend [18]. Alumina addition with Karnja bio diesel blend observed reduction in all the three major engine pollutant CO, HC and NOx [19]. The maximum blending up to 100ppm with Karnja bio diesel blend, CO and NOx found to be the lowest among all other blends under test, it was 0.02 % and 471 ppm respectively [19]. The main benefit of the use of manganese as fuel catalyst is that, it is not considered as an engine pollutant and also performance increased marginally. The exhaust emission of CO and NOx found to be reduced 37% and 4% respectively in comparison with conventional fuel with the addition manganese [20]. The metal Nanoparticles and Carbon Nano tube are mainly used as engine fuel catalyst, due to its effect of reduction in emission and increased performance, but long term stability has to be checked [21]. The addition of Titanium oxide has found to be better for the increment in engine power [21].

PHENOMENON OF COMBUSTION IN NANO FUEL

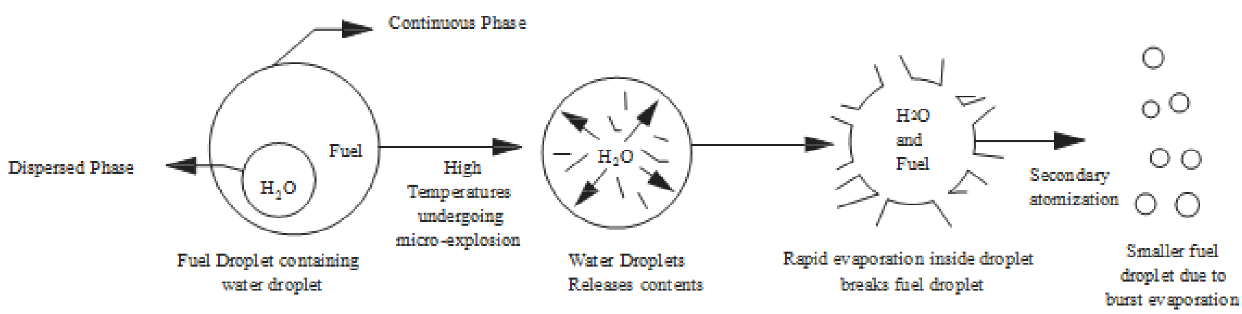

Figure 1: Schematic Sketch of Micro-Explosion Phenomenon of Water–Diesel Emulsion Fuel [22]

The combustion phenomenon observed in the Nanoparticles blended fuel somewhat differs from the normal combustion for water-emulsion. It found a rise in the peak pressure and HRR, longer ignition delay with high premixed phase in comparison with neat diesel and CNT blended water–diesel emulsion fuels [14]. As the boiling point of water is lower than diesel, the CNT added droplets has absorbed heat quickly to form water vapor and exploded through the surrounding oil layers, through the effect called ‘micro-explosion’. Nanoparticles added fuel affected by the secondary atomization which enhances thermal efficiency is shown in figure 1 [14]. The high surface to volume ratio is increased and also the effective

surfaces of the fuel droplet. Nanoparticles blended fuel may also undergo micro-explosion and secondary atomization, similar to the water–diesel emulsion fuel. This phenomenon could improve the catalytic combustion of CNT, and also increase the thermal efficiency of the fuel [22].

EFFECT ON COMBUSTION CHARACTERISTICS OF NANOPARTICLES:

The effect of the addition of Nanoparticles, in relation to the combustion properties like Ignition delay period, Heat Release rate (HRR) and P- θ diagram are as follows.

Ignition Delay and Heat Release Rate (HRR)

The addition of cerium oxide gave quicker combustion and reduced ignition delay compared to conventional fuel [1]. For alumina blended fuel, due to increase of surface area and at higher loads. high temperature ignition delay decreases [23]. Because of the high heat transfer coefficient due to alumina addition, HRR and exhaust gas temperature is higher [23]. It might be due to the chemical reaction of the Nanoparticles blending, HRR is the highest for Mahua BD20 +100ppm alumina blended fuel compare to Mahua BD and Diesel [12]. Nano aluminum particles produced reduction in ignition delays and very high metal combustion temperatures [13]. Due to addition of Nanoparticles reduced ignition delay and higher carbon combustion activation found, it accelerates complete combustion [24]. More fuel air mixing and uniform burning could have been improved [24]. The amount of heat release rate is 124.727 kJ/m3deg, 149.818 kJ/m3deg and 164.928 kJ/m3deg for diesel, CMNT25 and CMNT50, respectively [14],[25] . Because of the addition of the Nanoparticles, Cetane number has improved, surface area/volume ratio became high, and evaporation rate became high [14]. This could be due improved combustion properties like peak pressure, HRR, and reduced ignition delay [14]. The maximum HRR observed for Jatropha BD is 40.1 J/degree Crank Angle, whereas it is 35, 34.5, and 33.8 J/degree for Crank Angle at dosing level of 50ppm Alumina, 50ppm Carbon Nano tube and Alumina 25ppm + Carbon Nano tube 25ppm with Jatropha BD blends, respectively for the full load [14]. It was observed that improved heat release rate for the JME2S5W (2% surfactants and 5% water) fuel was observed when compared to that of JME2S5W25CNT (2% surfactants, 5% water and 25 ppm carbon Nano tube), JME2S5W50CNT (2% surfactants, 5% water and 50 ppm carbon Nano tube) and JME2S5W100CNT (2% surfactants, 5% water and 100 ppm carbon Nano tube) fuels. At the full load, the peak HRR for the JME fuel observed was 40.11 J/degree crank angle, for the other blends, it was in the range of 46 J/CA to 40 J/CA [26]. Biodiesel addition with Nano-additive contributed shorter ignition delay at higher injection pressure. However, it was found that injection timing effect is more prominent than injection pressure on ignition delay [27]. By addition of $FeCl_3$with biodiesel, ignition delay decreased to minimum of 100 CA. Due to addition of $FeCl_3$ enhanced Cetane number and catalytic effect which too causes decrease in physical delay. $FeCl_3$ added biodiesel has shown fastest combustion with duration of 52.8° Crank Angle at optimized operating condition, which somewhat is higher compared to that of diesel due to the enhancement of oxidation of hydrocarbons. The maximum HRR was observed with $FeCl_3$catalyst added biodiesel, in comparison to biodiesel without catalyst and also diesel [27]. Due to higher premixed combustion and higher delay in water emulsified, Diesel fuel observed and so peak pressure and HRR found to be higher compared to diesel [22]. The ignition delay reduced due to better atomization, increases in Cetane number and also increased surface area to volume ratio for CNT water emulsified Diesel fuel [22]. For the Karnja Bio fuel with Ce_2O_3 added blend, ignition delay was minimum, 5°, in comparison with Karnja Bio fuel 7° and diesel 8° [28].

Pressure vs Crank Angle (P- θ)

For P- θ curve, the peak pressure increased with an addition of cerium oxide and ethanol in diesel. The highest peak pressure is 10.2MPa for the cerium oxide. In comparison, Nano particles blended fuel, neat diesel stands at 8.4MPa

[1]. This is due to cerium oxide Nanoparticles higher combustion rate and lower HRR observed in comparison to diesel-biodiesel-ethanol blend. The HRR was observed highest for biodiesel blended fuel, 84 J/CA at bmep of 0.44MPa [1]. During combustion pressure rise before and after 70, before TDC for all the blends, a sharp increase is observed up to crank angle 70 after TDC in the case of the case of pure diesel and B20 blend. But for Al2O3 blended fuel, the increase in pressure up to crank angle 80, after TDC is due to the higher surface area of Nanoparticles and found to be increased in oxygen due to soya bean biodiesel. The peak pressure is 64.61 bar, 63.03 bar and 62.41 in the case of Al2O3 blended fuel, neat diesel and B20 respectively. Increment in peak pressure was found for all the blends as the load increased, with an increased fuel quantity also [23]. For Mahua BD20 100ppm alumina blended fuel pressure, it starts significantly from 9° before TDC and for neat diesel, it is 6°. For both the fuel increase in the in-cylinder pressure, it is observed up to 7° after TDC [12]. The pressure increased for Mahua BD20+100ppm alumina blended in comparison to the diesel fuel is due to the high surface contact area of the Al2O3nanoparticles and oxygenated blends. This is due to the addition of Mahua BD20 that enhances the rate of combustion [6]. The peak pressure 63.19 bar and 64.35 bar at full load for Mahua blended BD20 and Mahua blended BD20+100ppm Al2O3nanoparticles [12]. The cylinder peak pressure for the Jatropha BD at the full load observed is 72.3 bar compared to 69.5 bar, 69 bar and 68.5 bar for the dosing level of 50ppm Alumina, 50ppm Carbon Nano tube and Alumina 25ppm + Carbon Nano tube 25ppm with Jatropha BD blends, respectively [14]. Due to addition of CNT to JME emulsion blend decrease in pressure of cylinder, short premixed burning phase, increase in Cetane number and better combustion characteristics were found [26]. For full load condition, peak pressure for JME was 72.3 bar and for JME + 100 ppm CNT emulsion blend, it was 72.15 bar [26]. The main reason of decrease in peak pressure was due to the fact that physical and chemical delay was decreased because of the Nano particles [26]. With the addition of Aluminum A1, Boron B1, Iron F1 ignition property improved and thus peak pressure was reduced [11]. At full load, the peak pressure for the blends of Aluminum A1, Boron B1, Iron F1 and Diesel was 55, 59, 60 and 62 bar respectively [11]. The highest cylinder pressure of 75.8 bar at 366.10 Crank angle and 74.3 bar at 367.20 Crank angle was found with FeCl3 Nanoparticles with and without biodiesel at optimized operating condition[27]. The highest cylinder peak pressure was found for water-diesel emulsified fuel, it was 75.4 bar and lowest was for neat diesel, it was 69.8 bar [22]. For Nano particles blends of 25 ppm and 50 ppm with diesel emulsified blend, it was 73.5 bar and 71.1 bar at full load [22]. Here also due to short ignition delay, reduction in heat release rate and peak cylinder pressure for Nanoparticles added blends was found [22]. The highest heat release rate for water-diesel emulsion + 50 ppm Nano particles blend was 36.6 J/CA, for water-diesel emulsified fuel was 40 J/CA and for neat diesel 37.7 J/CA at full load [22]. Again, reduction in peak cylinder pressure is found due to shorter ignition delay. At full load for water diesel emulsion + 50 ppm Nano particles, peak pressure was 71.2 bar [22].

EFFECT OF NANO PARTICLES BLENDED FUEL ON PERFORMANCE

The due focus and discussion points from variious research papers include important Performance parameters like Specific fuel consumption, brake specific energy consumption and brake thermal efficiency.

Specific Fuel Consumption

Diesel-ethanol blends have lower calorific value as SFC is higher for these blends compared to neat diesel. The lowest SFC found was 0.3586 kg/kWh for cerium oxide Nanoparticles added fuel in comparison with other blends whereas for neat diesel, it was 0.3931kg/kWh [1]. The addition of cerium oxide Nano particles accelerated the combustion and hence the SFC found is lower for

the blends of Nanoparticles added fuel [1]. BSFC found 0.309kg/kWh for alumina blended biodiesel fuel, which was lower in comparison with neat diesel, biodiesel for Alumina blended fuel at full load [23]. This is due to alumina Nanoparticles which has more surface area to volume ratio and hence the BSFC is found to be minimum [23]. One more good result observed from Brake Specific Energy Consumption is that the energy input to develop unit power was also found minimum. For alumina blended biodiesel, it was 3.53, but for the B20 blend it was 3.7 and for neat diesel, it was found 4.33 [23]. The maximum decrease in SFC was found for Diesel + 50ppm carbon Multiwall Nano tube blend which is in comparison to diesel + 25ppm Carbon Multiwall Nano tube blend and neat diesel [24]. It was because of potential Nanoparticles blend, which increase higher surface area to volume ratio and in turn accelerate catalytic effect [14]. For Jatropha biodiesel blend with 25ppm carbon multi wall Nano tube and Alumina each, SFC was found to be 0.31kg/kwh whereas for Jatropha biodiesel, it was 0.37 kg/kWh [14]. At higher injection pressure, due to better mixing and higher atomization, SFC of carbon multi wall Nano tube blended biodiesel was lower than neat biodiesel at all load [26]. The BSFC was 0.301 kg/kWh for water emulsified JME + 100ppm Carbon Multi wall Nano tube blend at full load [26]. The reduction in ignition delay and high calorific values with addition of Nano particles is found lower SFC for its blends with Aluminum, Boron and Iron [11]. With FeCl3 blended biodiesel at 280 bar and 25.50 before TDC, lowest BSFC is found at 0.3kg/kWh in comparison to diesel and biodiesel blend in the investigation [27]. Brake Specific Energy Consumption, was also lower for the FeCl3 blended biodiesel in comparison with without catalyst blended biodiesel and neat diesel [27]. For full load, BSFC was found to be lowest at 0.29 kg/kWh for diesel-water emulsion with 50ppm Carbon Nano tube in comparison to other blends of Nano particles added diesel-water emulsion blend and neat diesel [22]. It could be due to higher surface area to volume ratio of Nano particles, the phenomenon of the micro-explosion effect, turbulent mixing enhances the combustion characteristics [22].

Break Thermal Efficiency (BTE)

Brake thermal efficiency was improved little with the addition of cerium oxide Nanoparticles at standard operating condition [1]. For Biodiesel blend, BTE was 15.8% and for Alumina blended biodiesel fuel, it was 17.9%, which was higher compared to neat diesel at full load [23]. The increase in BTE is mainly due to higher oxygen content and higher evaporation rate due to micro explosion of Nano particles droplets which has released full thermal energy [23]. The BTE increased 1.58% and 7.34% with Mahua BD+50ppm alumina blend and Mahua BD+100ppm alumina blend respectively [12]. This could be due to the addition of alumina Nanoparticles addition which enhances combustion catalytic activity due to more active surface of Nano particles [12]. With the addition of carbon multiwall Nano tubes, BTE increased because of more reactive surface which promoted higher chemical reactivity [24]. Maximum gain in thermal efficiency is observed for Jatropha BD+25ppm Alumina+25ppm CNT blend and maximum BTE was found to be 28.9%, whereas minimum BTE was 24.9% for Jatropha BD at full load condition [14]. CNT-JME emulsion fuels, water droplet in fuel absorbed heat quickly (due to low boiling point of water), and intensive secondary atomization observed [26]. Due to this maximum BTE 28.45% for JME-CNT+100ppm blend was noticed [26]. Due to addition of Nanoparticles enhancement in calorific value, complete combustion and reduced ignition delay, higher flame temperature was observed [11]. All of these factors led to catalytic combustion, increase in thermal efficiency with Aluminum, Iron and Boron Nanoparticles blended diesel fuel [11]. For FeCl3 blended biodiesel BTE, it was 30.9% at standard operating condition [27]. The gain in BTE is due to catalytic effect of FeCl3 Nanoparticles [27]. A maximum increase of 2.5% in the BTE was obtained when the dosing level of CMNT is 50 ppm [22]. Nanoparticles possessed high surface area and reactive surface that contribute to higher chemical process which enhance combustion process [22]. For diesel-water emuslsion+50ppm CNT, efficiency was 28.0% which was found maximum compare to other blends

Table 1: Comparison of Properties Nano Particles Blended Fuel

Author	Fuel blend	Type of Biodiesel	Nano Particle	Viscosity at 400C (cSt)	Density at 150C (kg/m3)	Flash Point (0C)	Fire Point (0C)	Cetane index/number	Calorific Value in MJ/kg
T shaafi et al [23]	Diesel	---	---	2.61	825	---	---	57	44.70
	Soya BD	---	---	4.78	865	---	---	49	41.20
	BD20	---	---	3.70	847	---	---	42	43
	D80SBD15E4S1	---	---	3.37	840	---	---	52	42.59
G R Kannan et al [27]	Diesel	---	---	2.41	828.2	49	55	56	42.11
	Biodiesel	Waste cooking Palm oil	---	4.56	866	170	190	66	38.034
	BD + 5µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.55	865.8	170	190	67.4	38.10
	BD+10µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.52	865.4	168	187	67.9	38.14
	BD+15µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.52	865.2	167	186	68.1	38.21
	BD+20µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.51	864.6	167	185	68.68	38.30
	BD+25µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.54	864.6	167	185	68.9	38.32
	BD+30µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.55	864.8	167	185	68.93	38.30
	BD+35µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.56	865.2	166	184	68.2	38.28
	BD+40µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.56	865.4	165	184	69.4	38.36
	BD+45µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.57	865.4	165	183	69.3	38.40
	BD+50µmol FBC	Waste cooking Palm oil	$FeCl_3$	4.57	865.4	165	183	69.6	38.43
J Basha et al [14]	JBD	Jatropha	---	5.25	895	85	---	53	38.88
	JBD25A	Jatropha	Alumina	5.31	896	84	---	54	39.22
	JBD50A	Jatropha	Alumina	5.35	897	82	---	56	39.53
	JBD25CNT	Jatropha	Carbon Nano tube	5.29	895.5	83	---	55	39.5
	JBD50CNT	Jatropha	Carbon Nano tube	5.33	897.9	81	---	57	39.78
	JBD25A25CNT	Jatropha	Alumina and Carbon Nano tube	5.36	895.2	81	---	57	39.99
J Basha et al [26]	JME	Jatropha	---	5.05	895	85	---	53	38.88
	JME2S5W	Jatropha	---	5.40	899.8	140	---	51	37.05
	JME2S5W25CNT	Jatropha	Carbon Nano Tube	5.43	897.2	130	---	54	37.28
	JME2S5W50CNT	Jatropha	Carbon Nano Tube	5.76	897.8	125	---	55	37.35
	JME2S5W100CNT	Jatropha	Carbon Nano Tube	5.91	899.4	122	---	56	37.85
J Basha et al [22]	Diesel	---	---	2.1	830	50	---	46	42.3
	D2S5W	---	---	3.32	847.6	56	---	44	40.5
	D2S5W25CNT	---	Carbon Nano Tube	3.38	848.2	55	---	46	40.7

	D2S5W50CNT	---	Carbon Nano Tube	3.42	848.9	54	---	47	40.9
C. S. Aalam et al[12]	Diesel	---	---	3	815	56	---	47	42
	Mahua Methyl Ester (MME)	Mahua	---	4.9	869	136	---	56	39.95
	MME20	Mahua	---	3.4	826	76	---	49	41.62
	MME+ANP50	Mahua	Alumina oxide	3.37	827.5	71	---	49.5	41.665
	MME+ANP100	Mahua	Alumina oxide	3.33	829	76	---	51	41.69
C. S. Aalam et al [25]	Diesel	---	---	---	815	58	---	47	42.00
	D+25CMNT	---	Carbon Multiwall Nano tube	---		61	---	48.4	42.426
	D+50CMNT	---	Carbon Multiwall Nano tube	---	823	65	---	49.6	42.731
V A M Selvan et al [1]	Diesel	---	---	2	830	50	56	46	42.30
	Ethanol	---	---	1.1314	790	13.5	---	6	25.18
	Castor oil	Castor oil	---	245	965	230	242	48	39.5
	D70 C10 E20	---	---	2.35	827.5	11	14	44.6	39.0
C. S. Aalam et al[24]	Diesel	---	---	2.54	833	50	---	52	---
	ZJME25	Zizipus jujube methyl ester	---	3.56	846	56	---	55	---
	25 ppm AONP– ZJME25	Zizipus jujube methyl ester	Aluminum oxide	3.39	849	57	---	57	---
	50 ppm AONP– ZJME25	Zizipus jujube methyl ester	Aluminum oxide	3.17	853	58	---	58	---
V A M Selvan et al [29]	Diesel	---	---	2	830	50	56	46	42.30
	Biodiesel	Castor oil	---	5.98	893	88	106	55.4	38.71
	Ethanol	---	---	1.1314	790	13.5	-	6	25.18
	E20-Diesterol (Diesel:Biodiesl:ethanol;70:10 :20)	Castor oil	---	2.35	827	11	14	45.25	40.10

EFFECT OF NANO PARTICLES BLENDED FUEL ON EMISSION

For emission purpose CO, HC, NOx and Smoke are mainly analyzed from the relevant paper.

CO

For Biodiesel ethanol blend, CO emission was reduced in comparison with neat diesel [23]. Also, for the cerium oxide blended fuel, it was further decreased in comparison to neat diesel [23]. As the load increased CO emission was decreasing for the alumina blended fuel [6]. At full load, due to higher rate of atomization, combustion process increased [6]. Reduction in CO emission was found to be 48% for the alumina Nanoparticles blended Mahua BD20, compared to Mahua BD20 [12]. The main reason of reduction in CO emission was Alumina Nanoparticles which acted as oxygen catalyst [12]. It was found that little rise in CO emission level due to addition of Carbon Multi wall Nano tube [25]. For Carbon Multi wall Nano tube 25ppm blend CO emission was, 0.67 % (by volume) and for Carbon Multi wall Nano tube 50ppm blend, 0.75 % (by volume) in comparison with diesel which was 0.49% (by volume) [25]. With the addition of CNT, lower ignition delay was found, proper mixing of fuel air and also uniform burning which contributed complete combustion [26]. Maximum CO emission was found for Jatropha Methyl ester emulsion fuel was 0.75% (by volume) whereas for Jatropha Methyl ester emulsion fuel with 100ppm CNT, it was decreased to 0.06% (by volume) [26]. For diesel blend with aluminum A1 and Iron F1 Nano fuel, it was found that 30% CO emission increased at lower load [11]. But at higher load,

CO emission was reduced by 25-40% in comparison with diesel [11]. For the blend of Boron B1 there was no change in CO emission compared to Diesel [11]. It was found that due to higher oxygen content and increase in Cetane number, there was reduction in CO emission at standard operating condition [27]. For Biodiesel with FeCl3 catalyst added fuel blend, minimum CO emission found, it was 1.9 g/kWh, lowest for the study [27]. The main reason of this reduction in CO emission was due to the acceleration in oxidation of CO to CO2 [27]. For CNT blended water emulsified Diesel fuel, secondary atomization CO emission decreased slightly in comparison to diesel and water emulsified fuel [22].

HC

Hydrocarbon combustion [17]: $(2x+y)CeO_2 + C_xH_y \rightarrow \left[\frac{(2x+y)}{2}\right] Ce_2O_3 + \frac{x}{2}CO_2 + \frac{y}{2}H_2O$

The HC emission was decreased in comparison to neat diesel, for cerium oxide blended fuel [1]. The main reason of reduction in HC emission is due to the usage of oxygenated catalyst which promotes complete combustion [1]. The amount of unburned HC emission was found to be lower as the higher surface area of Nano particle improved combustion for Biodiesel 20 blend [6]. HC emission was reduced to 26.04%. Here again the reason is same that Nano particles increased oxygen amount in fuel which enhanced the complete combustion [12]. With the addition of carbon multi wall Nano tube, there is an increase in amount of carbon content in the fuel blend, due to which temperature inside the combustion chamber also increased [25]. Similarly, the HC emission was found to be increasing for Carbon Multi wall Nano Tube 25 ppm and 50ppm, it was 120ppm and 135ppm respectively [25]. For HC emission, it was observed 46ppm for Jatropha BD 25ppm Alumina + 25ppm Carbon multi wall Nano tube blend [8]. Emulsified fuel has water content, so the temperature of inside the combustion is lower hence the increment in HC emission was observed [11]. But due to addition of CNT, there was secondary atomization observed and due to this for CNT blended fuel, there was little reduction in HC emission [11]. At full load, HC emission for Jatropha BD was observed at maximum of 63 and for Jatropha BD emulsion with 100ppm, CNT blend was minimum 57 for the test [11]. For biodiesel, HC emission reduced due to higher oxygen and increase in Cetane number at any operating condition in the range [11]. For biodiesel, THC was noted with 0.0236 g/kWh at specific condition [15]. For FeCl3 catalyst added fuel blend, THC was 26.6%, for without addition of FeCl3 catalyst it was 63.7% [15]. Due to this, higher surface area to volume ratio, complete combustion and better catalytic characteristics observed [12]. So the HC emission reduced to somewhat extent for CNT blended water emulsion blended fuel [12].

Smoke

The least smoke coefficient found was 1.273, for cerium oxide Nanoparticles due to oxygenated fuel which led to better combustion [1]. For alumina blended fuel, 3.3% reduction in smoke emission and for BD20 blend, 2.2% increase in smoke emission compared to neat diesel was observed at full load [5]. More importantly, smoke reduced considerably due to oxygen enriched Biodiesel fuel and aluminum oxide addition in fuel [12]. Maximum reduction was found for the Mahua BD20+Alumina Nano Particle 100ppm blend, it was 50.5HSU at full load for particular test [12]. It was observed that 10-15% reduction in smoke at full load addition [14],[25]. It was found that shorter ignition delay due to addition of Nanoparticles [14],[25]. Also, it was observed that reduction in smoke increased at higher concentration of CMNT [14],[25]. For Nanoparticles added biodiesel fuel blend went with faster evaporation rate, decrease in ignition delay and improved combustion characteristics. Due to this, reduction in smoke was found for the blend of Nanoparticles [14]. The smoke opacity found 57% for Jatropha BD with dose of 25 ppm Alumina + 25 ppm Carbon Nano Tube, whereas it is 60

%, 58 % and 67 % for Jatropha BD with dose of 50 ppm Carbon Nano Tube, 50 ppm Alumina and Jatropha BD at the full load, respectively [14]. With the addition of CNT, smoke reduced compared to JME-emulsion fuel. It was mainly due to reduction in soot formation and secondary atomization [26]. The smoke observed for JME emulsion with 100ppm CNT, was minimum [26]. Reduction in soot and improved reactive mixture was found due to secondary atomization effect of CNT blended emulsified fuel. At the full load, lowest smoke opacity observed was 49%, for the JME water emulsion with 100 ppm CNT blend [26]. Due to higher oxygen content in the fuel and less Sulphur content, smoke emission was less because of the complete hydrocarbon oxidation for all Biodiesel blends [27]. It was found that 6.9% smoke reduced for FeCl3 catalyst added biodiesel blend in comparison with, without catalyst blend [27]. The main reason of this could be the use of Nanoparticles acted as a oxidation catalyst [27]. Due to addition of CNT with water diesel emulsion blend, ignition delay was found to be decreasing and also due to better mixing of air fuel, smoke was also decreasing [12]. Maximum lower level of smoke was found to be 51% for water diesel emulsion with 50ppm CNT blend and for water diesel emulsion, it was 59%, for neat diesel 85% [12].

NO

For NO reduction, chemical reaction for cerium oxide added blend follow as per the reaction[17]:

$$Ce_2O_3 + NO \rightarrow 2CeO_2 + \frac{1}{2}N_2$$

For ethanol blended biodiesel, due to long delay period and oxygenated fuel, NO emission observed, which is higher compared to diesel [1]. The lowest NO emission, was 250ppm, found for neat diesel at optimized operating condition for diesel [1]. At full load condition minimum NOx emission found for neat diesel, was 1792 ppm for neat diesel, whereas maximum NOx emission found for B20 alumina blended fuel, it was 1971 ppm [5]. Due to higher temperature in cylinder, NOx emission was higher for B20 and Alumina blended fuel compare to diesel [5]. NOx emission increased because of the use of aluminum oxide Nano particles. It gave complete combustion, higher HRR and also higher peak pressure [12]. Maximum NOx emission was found in the cases of alumina blended BD 20 for 100 ppm respectively [12]. With the increase in the addition of Carbon Multiwall Nano tube NOx emission was decreased. NOx emission for diesel was 870 ppm, for 25 ppm Carbon Multiwall Nano tube 740 ppm and for 50 ppm Carbon Multiwall Nano tube 630 ppm [25]. Reduction in NOx was found due to low ignition delay. Due to this, much higher amount of fuel inside the cylinder during combustion so the NOx reduction was found [14]. The lowest NOx emission found for JBD with 25 ppm Alumina and 25 ppm CNT blends, was 985 ppm and highest for JBD, was 1282 ppm [14]. With use of water in the Jatropha emulsion fuel blend, NOx emission significantly decreased due to lower temperature during the combustion in the cylinder [26]. At the full load, the magnitude of NOx emissions found was 1282 ppm, 1001 ppm, 973 ppm, 961 ppm and 910 ppm for the Jatropha BD, Jatropha BD water emulsion, Jatropha BD water emulsion with 25 ppm,50 ppm and 100ppm CNT fuels respectively [26]. An increase of 5% and 3% was observed in NOx emission with diesel with aluminum blend A1 and Iron blend F1 as compared to diesel and Boron B1 Nano fuels [11]. In comparison with Diesel, emission was increasing in terms of weight by 12%, 9%, and 8%. This was observed for Iron F1, Boron B1 and aluminum A1 Nano fuels, respectively, approximately [11]. For the FeCl3 catalyst added biodiesel NO emission was increased, 4.1 % higher compared to without addition of FeCl3 catalyst at optimized condition. But, it was 11.3% lower compared to diesel [27]. The increment of NO emission was due to FeCl3 catalyst, which oxidizes the nitrogen into nitric oxide [27]. For the water diesel emulsion blend, NOx emission was lower compared to diesel due to heat sink effect caused by the water droplets in the emulsion. Due to reduced ignition delay and lower heat absorption during combustion lower combustion temperature

was found [22]. NOx emission for diesel water emulsion with 50 ppm CNT was 970ppm and for diesel it was 1340 ppm at full load [22].

Below shown table 2 give all the information regarding type of Nano particles, size, preparation method of blend and device used, dosage level or % concentration in the blends. It also gives details of engine specification, its related parameter and also the findings of it.

All the important Nano particles physical characteristic and important performance parameter which were discussed in above review is tabulated in below table with comparison.

Table 2: Summary of Influence of Nano Particles on Biodiesel Fuel for Engine

Author	Nano particles	Size of Nano particles	Nano fluid preparation	Device used for fluid preparation	Dose of Nano particles in mg/L	Engine specification	Engine speed	Types of Engine Loading device	Conclusion
shaafi et al [23]	Alumina	50 nm	Two steps	Ultrasonicator	100	4-S, Single Cylinder,4.4 kW, Direct Injection, Air Cooled	1500 rpm (constant speed)	AC generator and resistance load bank using a rheostat	Reduction in CO, CO2, UBHC for the alumina blended fuel at full load, increase in NOx emission, maximum cylinder pressure and HRR
R Kannan et al [27]	$FeCl_3$	---	Two steps	Mechanical stirrer	5 to 50	4-S, Single Cylinder,5.2 kW, Solid /Direct Injection, Water Cooled	1500 rpm	Electrical alternator	NO, slightly higher CO2. CO and THC decreased but smoke emission slightly. Higher cylinder gas pressure, HRR and shorter ignition delay
J Basha et al [14]	Alumina	51 nm	---	Ultrasonicator (40 kHz, 120 W for 30 min)	25, 50	Single Cylinder,4.4 kW, Direct Injection, Air-Cooled	1500 rpm	AC Alternator	Quick evaporation, better ignition, higher surface/ volume and heat conduction also good.
	Carbon nano tube	16 nm	Three stages	Mechanical Agitator and Ultrasonicator	25, 50				

									BTE and BSFC improved. NOx and smoke emission were also reduced and also ignition delay.
J Basha et al [26]	Carbon Nano Tube	16 nm	---	Mechanical Agitator (2000 rpm,30 min)	25, 50,100	Single cylinder,4-S,4.4 kW, Air cooled, constant speed, Direct injection	1500	AC Alternator	Micro explosion and secondary atomization were found for CNT blended fuels. Due to this NO and Smoke reduced. BTE very high and peak pressure reduced with high HR
J Basha et al [22]	Multiwall Carbon Nano Tube	16 nm	Two steps	Mechanical Homogenizer set (2500 rpm,15 min, at 30^0C) and Ultrasonicator (40 kHz, 120W for 30 min)	50	Air cooled, Single cylinder, 4-S, Direct injection system, type,4.4 kW	1500	AC Alternator	The cylinder peak pressure is lower, BTE, BSFC improved and also NOx emission is considerably less
C. S. Aalam et al[12]	Alumina oxide (spherical shaped)	32 to 48 nm	---	Ultrasonicator and Homogenizer	50 and 100	Single cylinder, Vertical, water cooled, four strokes,3.7 kW	1500	Eddy current dynamometer	Peak pressure, CV and HRR increased. Reduction in ignition delay, flash point was observed. High reduction in fuel consumption, a little increme

									nt in BTE, reduced HC and CO but NOx emissions increased.
C. S. Aalam et al [25]	Carbon Multiwall nano tube	2 to 50 nm	---	Mechanical Homogenizer and Ultrasonicator	25 and 50	Single cylinder, Vertical, water cooled, four strokes,5.2 kW	1500	Eddy current dynamometer	BTE improved, NOx and smoke reduced, High cylinder gas pressure and HRR at optimized operating conditions.
V A M Selvan et al [1]	Cerium oxide	32 nm	---	High speed blending and Ultrasonic bath	25	single cylinder, 4 stroke, direct injection, VCR (compression ratio 5:1 to 20:1), Water cooled,3.7 kW	1500	Eddy current dynamometer	For the same blend BTE was lower than diesel for blends at all the loads and a little improvement was found for the cerium oxide blended fuel
C. S. Aalam et al [24]	Aluminum oxide	31.6 to 47.5 nm	---	Mechanical Homogenizer and Ultrasonicator	25 and 50	Single cylinder, Vertical, water cooled, four strokes,5.2 kW	1500	Eddy current dynamometer	SFC and exhaust emissions reduced for all loads. BTE and HRR increased drastically. NOx emission increased
V A M Selvan et al [29]	Cerium oxide and single wall Carbon Nanotube	32nm	---	Mechanical Homogenizer and Ultrasonic Bath	25,50,100	single cylinder, 4 stroke, direct injection, VCR (compression ratio 5:1 to 20:1), Water	1500	Eddy current dynamometer	With Nano particles, BTE and peak pressure

						cooled,3.7 kW			increased, less Ignition delay and Combustion stated early. CO was high, HC and Smoke decreased

CONCLUSIONS

In this paper, recent progress for the Nanoparticles and its effect on fuel combustion process is mainly focused. Also, engine performance and testing for diesel engine is also discussed in detail. In depth data collection for the parameters of the Nano particles on the bases of comparison was presented in this paper. The major conclusions from all the research paper is listed below.

- Nanoparticles addition with diesel fuel shows a completely different combustion process in comparison to convention fuel. In combustion micro explosion and secondary atomisation is observed which mainly improved the combustion and performance characteristics. It is observed that shorter ignition delay and higher surface to volume ratio of droplet, increases evaporation rate.
- Due above mention fact, engine performance improved significantly with the Nano particles addition up to some extent of dosing level but after certain level dosing not so effective. So, level of concentration for the particular blend is limit for dispersion.
- At the same peak, for diesel blend, temperature is increased due to which NOx also increased.
- For the blends of biodiesel, combustion temperature is low compared to diesel and hence the NOx emission is found to be reducing.
- For the NOx emission reduction, Emulsification is the one of the best alternate but at the same time, it is found that it reduced the performance of an engine due the heat sink effect of water.
- Due to complete combustion of fuel, the CO emission also reduces except for the blend with magnetic Nano fluid.
- Stability of the dispersion of the Nanoparticles with the fuel is to be analysed further.
- Its impact on the environment is to be researched separately.

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